

DESIGN AND DEVELOPMENT OF A THOUGHT  
CONTROLLED INTELLIGENT ROBOT CHAIR WITH  
COMMUNICATION AID

SATHEES KUMAR NATARAJ

UNIVERSITI MALAYSIA PERLIS

2016



**DESIGN AND DEVELOPMENT OF A THOUGHT  
CONTROLLED INTELLIGENT ROBOT CHAIR  
WITH COMMUNICATION AID**

by

**SATHEES KUMAR NATARAJ  
(1240610751)**

A thesis submitted  
In fulfillment of the requirements for the degree of  
Doctor of Philosophy

**School of Mechatronic Engineering  
UNIVERSITI MALAYSIA PERLIS**

**2016**

## ACKNOWLEDGEMENT

The successful completion of this thesis work relies on the influence of many people who have generously given their time and energy in specific ways. I take this opportunity to express my gratitude and thanks to each of you who have been a part of this PhD journey. First and foremost, I would like to express my sincere thanks to the Vice Chancellor of Universiti Malaysia Perlis, Brigedier Jeneral Dato Professor Dr. Kamarudin Hussin for his constant encouragement and facilities provided at the university for the completion of this research work.

I would like to express my sincere gratitude to my advisor and mentor Prof. Dr. Paulraj M. P. for the continuous support of my PhD study and research, for his patience, persistence, visualization, and immense knowledge. During the research, Prof Paul style of guidance had made me to gain knowledge on many aspects; Prof. Paul will not give you answers for your research problems instead he will put you on a path to seek answers. I have been fortunate to have a supervisor who gave me the opportunity to develop my individuality and self-sufficiency during the study. I am indebted to him for sharing his vast knowledge and experience with me and for teaching me to write research papers. I am happy to say that one could not wish for a better or friendlier supervisor.

I would also like to extend my warmest gratitude to my second supervisor Prof. Dr. Sazali Bin Yacob, UniKL MSI for his motivational words, understanding and caring advices, convictions, and making me to realize my true potential. I extend my boundless appreciation to Prof Sazali for the valuable comments, discussions and ideas to register my research in National Medical Research Register (NMRR) and Malaysian Research Ethics Committee (MREC) for permitting the data collection process for this research at UniMAP, from which my research work have been greatly benefitted.

I am also very grateful to my third supervisor Prof. Dr. Abdul Hamid Bin Adom for his support and facilities provided at the school, for the completion of this work. I thank him for constantly encouraging me to complete this research work.

I take this time to thank the Dean, School of Mechatronic Engineering Assoc. Prof. Dr. Abu Hassan bin Abdullah, the program chairman Dr. Ruslizam bin Daud and former program chairman Dr. Cheng Ee Meng for their cooperation and administrative assistance through this course of study. I also very grateful to Dr. Khaled Mohamed Helmy Abd El Aziz, Hospital Tunku Fauziah, Perlis, Malaysia and Assoc. Prof. Dr. Mohammad Iqbal Bin Omar, School of Mechatronic Engineering, Univerisiti Malaysia Perlis, Perlis,

Malaysia, for their generous contributions of data inspection, fruitful suggestions, advices, and for sharing knowledge.

I wish to thank the Malaysian Ministry of Higher Education for providing the research grant: 90013-00012 under the Prototyping Research Grant Scheme (PRGS), which funded this research work. I also extend my sincere thanks to UniMAP for providing a financial support through a Graduate Assistantship.

I have been fortunate to have many friends who cherish me despite my eccentricities. I would never forget all the chats and beautiful moments I shared with some of my friends. They were fundamental in supporting me during these stressful and difficult moments. I thank all my hometown friends and Malaysian friends for their entertaining friendship and moral support to accomplish this thesis. I also thank all the members of Intelligent Signal Processing Research Cluster and other research clusters for their endless support and motivation.

Finally, I owe my sincere thanks to my parents, Mr. G. Nataraj and Mrs. N. Vimala, sister, Mrs. M. Sandhiya for their unconditional support, both financially and emotionally throughout my research work, still being 2500 miles away from me. In particular, the patience and understanding shown by my family during the honors year is greatly appreciated that has made me who I am now. I know, at times, my temper is particularly trying.

Last but not least, I am deeply thankful to different divinities existing in the universe by the principal concept of faith for successfully completing the research.

*...Thank you all.*

Sathees Kumar Nataraj

## TABLE OF CONTENTS

<b>CONTENTS</b>	<b>PAGE NO.</b>
<b>THESIS DECLARATION</b>	<b>i</b>
<b>ACKNOWLEDGEMENT</b>	<b>ii</b>
<b>TABLE OF CONTENTS</b>	<b>iv</b>
<b>LIST OF TABLES</b>	<b>xi</b>
<b>LIST OF FIGURES</b>	<b>xiii</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xv</b>
<b>LIST OF SYMBOLS</b>	<b>xviii</b>
<b>ABSTRAK</b>	<b>xxi</b>
<b>ABSTRACT</b>	<b>xxiii</b>
<b>CHAPTER 1 INTRODUCTION</b>	
1. 1 Preface	1
1. 2 Research Background	1
1. 3 Problem Statement	3
1. 4 Research Objectives	5
1. 5 Scope of the Thesis	7
1. 6 Organization of Thesis	8
<b>CHAPTER 2 LITERATURE REVIEW</b>	
2.1 Introduction	11
2.2 Differentially Enabled (DE) Communities and Their Basic Needs	12
2.3. Approach to Provide Assistive Technologies for DE Patients	14
2.3.1. Augmentative and Alternative Communication	15
2.4. Biosignals Based Assistive Devices for DE Communities	17
2.4.1. Electromyogram Signals Based Assistive Devices	17

2.4.2.	Electrooculogram Signals Based Assistive Devices	18
2.4.3.	Electroencephalogram and Hybrid BMI Systems	19
2.5.	Description and Classifications of BMI systems	26
2.6.	BMI for Speech Communications and Navigation	28
2.6.1.	BMI for Speech Communication	30
2.6.2.	Types of Elicitation Protocol for BMI-SC	32
2.6.2.1.	BMI-SC Based on Visually Evoked Potentials	34
2.6.2.2.	BMI-SC Based on the P300 Event-Related Potential	35
2.6.2.3.	BMI-SC Based on Slow Cortical Potentials	36
2.6.2.4.	BMI-SC Based on Thought Evoked Potentials	37
2.6.3.	BMI for Wheelchair Navigation	39
2.6.4.	Types of Elicitation Protocol for Wheelchair Navigation	42
2.6.4.1.	BMI-N Based on Visually Evoked Potentials	44
2.6.4.2.	BMI-N Based on the P300 Event-Related Potential	45
2.6.4.3.	BMI-N Based on Thought Evoked Potentials	46
2.7.	Signal Processing Methods and Classification Techniques	47
2.7.1.	Feature Extraction Techniques for BMI-SC and BMI-N	48
2.7.2.	Feature Classification Methods for BMI-SC and BMI-N	53
2.8.	Motivation towards Intelligent Robot Chair with Communication Aid	55
2.9	Summary	57
 <b>CHAPTER 3 DATA ACQUISITION AND PRE-PROCESSING</b>		
3.1	Introduction	59
3.2	Methodology	59
3.2.1	IRCC-Customized Classification System	61
3.2.2	IRCC-Generalized Classification System	63

3.3	IRCC Database	65
3.3.1	Ethics Statement	66
3.3.2	Subject Inclusion and Exclusion Criteria	67
3.3.3	Instructions to Subjects before Data Capturing	69
3.3.4	EEG Data Acquisition and Electrode Placement	69
3.3.4.1	Data Acquisition Tasks	71
3.3.4.2	Experimental Setup	71
3.3.4.3	Selection of Electrode Channels	72
3.3.5	Thought Evoked Potentials Paradigm	74
3.3.5.1	TEP Data Collection Procedure	76
3.3.6	Visually Evoked Potentials Paradigm	78
3.3.6.1	VEP Data Collection Procedure	80
3.3.7	Data Validation using Analysis of Variance	82
3.3.7.1	Framework I (Electrode Locations)	83
3.3.7.2	Framework II (Tasks)	88
3.4	Pre-processing of EEG signals	92
3.4.1	Segmentation of Frames	93
3.4.2	Frequency Band Signals	94
3.5	Summary	96
<b>CHAPTER 4 FEATURE EXTRACTION AND FEATURE CLASSIFICATION</b>		
4.1	Introduction	97
4.2	Higher Order Statistics	100
4.2.1	Bispectrum Estimation	101
4.2.2	Feature Extraction Algorithm to Extract the BM and BE Features	105
4.3	Cross-Correlation Features	106

4.3.1	Statistical Features using Auto-Correlated Frame Wise Spectral Bands	107
4.3.2	Feature Extraction Algorithm to Extract $M_{CFW}$ and $SD_{CFW}$ features	109
4.3.3	Statistical Features using Cross-Correlated Two Consecutive Frame based Spectral Bands	110
4.3.4	Feature Extraction Algorithm to Extract $M_{CF}$ and $SD_{CF}$ features	112
4.3.5	Statistical Features using Cross-Correlated Frame Based Combination of Spectral Bands	113
4.3.6	Feature Extraction Algorithm to Extract $M_{CFB}$ and $SD_{CFB}$ features	115
4.3.7	Statistical Features using Cross-Correlated Frame Based Combination of Electrode Channels	116
4.3.8	Feature Extraction Algorithm to Extract $M_{CEC}$ and $SD_{CEC}$ features	118
4.4	Band Power Features	120
4.4.1	Sum of the Powers	121
	4.4.1.1 Sum of the Powers in Each Frequency Band	121
	4.4.1.2 Sum of All the Powers	122
4.4.2	Relative Powers of Frequencies	122
	4.4.2.1 Sum of Relative Powers in Each Frequency Band	123
	4.4.2.2 Sum of All the Relative Powers	124
4.4.3	Differential Asymmetry	124
	4.4.3.1 Sum of Differential Asymmetry in Each Frequency Band	125
	4.4.3.2 Sum of All the Differential Asymmetry	125
4.4.4	Rational Asymmetry	126
	4.4.4.1 Sum of Rational Asymmetry in Each Frequency Band	126
	4.4.4.2 Sum of All the Rational Asymmetry	127
4.4.5	Change in Powers of Frequencies	127
	4.4.5.1 Change in Powers in Each Frequency Band	128
	4.4.5.2 Sum of All Change in Powers	128

4.5	Power Spectral Density	133
4.5.1	Feature Extraction Algorithm to Extract the AP Features	135
4.6	Feature Processing	136
4.6.1	Output Labeling	136
4.6.2	Feature Normalization and Randomization	137
4.6.3	Segmentation of Feature Set	138
4.6.3.1	Ten Fold Cross Validation	138
4.7	Feature Classifiers	139
4.7.1	Multilayer Neural Network Classifier	140
4.7.1.1	Architecture and Design of Multilayer Feed Forward Neural Network	141
4.7.1.2	Training Multilayer Feed Forward Neural Network	142
4.7.1.3	Choice of Neural Network Parameters	144
4.7.2	Support Vector Machines Classifier	145
4.7.2.1	Description of SVM-RBF Kernel Algorithm	146
4.7.2.2	Choosing SVM Parameters	148
4.7.3	K-Nearest Neighbor Classifier	149
4.8	Classifier Performance Validation and Measures	150
4.8.1	Performance Measures	150
4.8.2	Confusion Matrix	150
4.9	Summary	151
<b>CHAPTER 5 RESULTS AND DISCUSSION</b>		
5.1	Introduction	152
5.2	Performance Comparison of the IRCC-CC System	152
5.2.1	Performance of the CC-TEP Features using MLNN, SVM-RBF and KNN	153
5.2.1.1	Performance of the Bispectrum Features using CC-TEP	153

5.2.1.2	Performance of the Cross-Correlation Features using CC-TEP	155
5.2.1.3	Performance of the Band Power Features using CC-TEP	157
5.2.1.4	Performance of the PSD Features using CC-TEP	160
5.2.1.5	Comparison of the CC-TEP Classification Results	161
5.2.2	Performance of the CC-VEP Features using MLNN, SVM-RBF and KNN	163
5.2.2.1	Performance of the Bispectrum Features using CC-VEP	164
5.2.2.2	Performance of the Cross-Correlation Features using CC-VEP	165
5.2.2.3	Performance of the Band Power Features using CC-VEP	168
5.2.2.4	Performance of the PSD Features using CC-VEP	172
5.2.2.5	Comparison of the CC-VEP Classification Results	173
5.2.3	Performance Comparison between IRCC-CC-TEP and IRCC-CC-VEP Systems	174
5.3	Performance Comparison of the IRCC-GC System	175
5.3.1	Performance of the GC-TEP Features using MLNN, SVM-RBF and KNN	175
5.3.1.1	Performance of the Bispectrum Features using GC-TEP	176
5.3.1.2	Performance of the Cross-Correlation Features using GC-TEP	177
5.3.1.3	Performance of the Band Power Features using GC-TEP	179
5.3.1.4	Performance of the PSD Features using GC-TEP	183
5.3.1.5	Comparison of the GC-TEP Classification Results	183
5.3.2	Performance of the GC-VEP Features using MLNN, SVM-RBF and KNN	187
5.3.2.1	Performance of the Bispectrum Features using GC-VEP	187
5.3.2.2	Performance of the Cross-Correlation Features using GC-VEP	188
5.3.2.3	Performance of the Band Power Features using GC-VEP	190
5.3.2.4	Performance of the PSD Features using GC-VEP	194
5.3.2.5	Comparison of the GC-VEP Classification Results	194

5.3.3	Performance Comparison between IRCC-GC-TEP and IRCC-GC-VEP System	198
5.4	MATLAB Graphical User Interface for the IRCC System	198
5.5	Summary	200
<b>CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS</b>		
6.1	Introduction	201
6.2	Summary of Findings	201
6.3	Research Contributions	203
6.4	Future Work	205
	<b>REFERENCES</b>	207
	<b>Appendix A</b>	233
	<b>Appendix B</b>	235
	<b>Appendix C</b>	241
	<b>LIST OF PUBLICATIONS</b>	281
	<b>LIST OF AWARDS</b>	283

©This item is protected by original copyright

<b>NO.</b>	<b>LIST OF TABLES</b>	<b>PAGE NO.</b>
2.1	Characteristics of frequency bands in the neurophysiological signal	20
2.2	Summary of biosignal based applications and its characteristics.	24
2.3	Summary of control signals and their characteristics	27
2.4	Summary of control paradigm based BMI-S studies	33
2.5	Summary of control paradigm based BMI-N studies	43
2.6	Summary of feature extraction methods for BMI-SC and BMI-N	50
3.1	ANOVA test results for channel wise comparison using IRCC-TEP database (Maximum of ten trials)	84
3.2	ANOVA test results for channel wise comparison using IRCC-VEP database (Maximum of ten trials)	86
3.3	ANOVA test results for task wise comparison using IRCC-TEP database (Maximum of ten trials)	88
3.4	ANOVA test results for task wise comparison using IRCC-VEP database (Maximum of ten trials)	90
4.1	Features Generated from FFT	130
5.1	Mean classification results using bispectrum features (CC-TEP)	154
5.2	Mean classification results using cross-correlation features (CC-TEP)	156
5.3	Mean classification results using band power features (CC-TEP)	159
5.4	Mean classification results using PSD features (CC-TEP)	161
5.5	Performance Comparison of IRCC-TEP Classifiers Using Maximum Classification Accuracy	163
5.6	Mean classification results using bispectrum features (CC-VEP)	165
5.7	Mean classification results using cross-correlation features (CC-VEP)	167

<b>NO.</b>	<b>LIST OF TABLES</b>	<b>PAGE NO.</b>
5.8	Mean classification results using band power features (CC-VEP)	170
5.9	Mean classification results using PSD features (CC-VEP)	172
5.10	Performance Comparison of IRCC-VEP Classifiers Using Maximum Classification Accuracy	174
5.11	Performance of GC-TEP using BM and BE Features	176
5.12	Performance of GC-TEP using cross correlation features	178
5.13	Performance of GC-TEP using band power features	181
5.14	Performance of GC-TEP using PSD features	183
5.15	Confusion matrix for the maximum classification accuracy of 91.27 % (IRCC-GC-TEP-CEC-SD) using MLNN classifier	185
5.16	Confusion matrix for the minimum classification accuracy of 68.57 % (IRCC-GC-TEP-DA) using KNN classifier	185
5.17	Performance of GC-VEP using BM and BE Features	187
5.18	Performance of GC-VEP using cross correlation features	189
5.19	Performance of GC-VEP using band power features	192
5.20	Performance of GC-VEP using PSD features	194
5.21	Confusion matrix for the maximum classification accuracy of 90.7 % (IRCC-GC-VEP-CEC-SD) using MLNN classifier	196
5.22	Confusion matrix for the maximum classification accuracy of 73.41 % (IRCC-GC-VEP-DA) using SVM-RBF classifier	196

<b>NO.</b>	<b>LIST OF FIGURES</b>	<b>PAGE NO.</b>
2.1	Classical BMI system for communication and navigation	29
3.1	Block diagram of the intelligent robot chair with communication aid (IRCC)	60
3.2	A flowchart for IRCC-Customized Classification (IRCC-CC) System	62
3.3	A flowchart for IRCC-Generalized Classification (IRCC-GC) System	64
3.4	A flowchart for the development of IRCC database	66
3.5	Experimental setup during the acquisition of tasks to command IRCC	70
3.6	Representation of the electrode positions for IRCC data acquisition	72
3.7	Preliminary representation of the tasks (10.0 s) for subject to conduct the asynchronous data acquisition process	75
3.8	A typical EEG signal acquired while performing “LEFT” task using TEP	76
3.9	Sequence of steps followed in the TEP data collection procedure	76
3.10	A flowchart for TEP data acquisition	78
3.11	Representation of the tasks (12.0 s) for subject to conduct the VEP data acquisition process	79
3.12	Raw EEG signal acquired while performing “LEFT” task of Subject 1 using VEP	80
3.13	Sequence of steps followed in the VEP data collection procedure	80
3.14	A flowchart procedure for VEP data acquisition	82
3.15	(a). The frequency domain plot of ‘Left’ task EEG signal	93
3.15	(b). The frequency domain plot of ‘Left’ task EEG signal filtered by the IIR notch filter	93
3.16	A raw EEG signal blocked into frames (512 samples) with 50 % overlap	94
3.17	(1) Delta band ( $\delta$ ), (2) Theta band ( $\theta$ ), (3) Alpha band ( $\alpha$ ), (4) Beta band ( $\beta$ ), (5) Gamma 1 ( $\gamma_1$ ) and (6) Gamma 2, $\gamma_2$ for the ‘LEFT’ task	95
4.1	Overview of the feature extraction algorithms used in IRCC system	99
4.2	Bispectrum magnitude (Non-redundant region, $\Omega$ ) for the EEG signals	103

<b>NO.</b>	<b>LIST OF FIGURES</b>	<b>PAGE NO.</b>
4.3	MLNN architecture for the IRCC system	142
4.4	Hyperbolic tangent activation function	144
4.5	Separating hyperplane using SVM for a simple two class problem	146
5.1	Comparison of maximum classification results of CC-TEP classifiers (Within subjects)	162
5.2	Comparison of maximum classification results of CC-VEP classifiers (Within subjects)	173
5.3	Comparison of maximum classification accuracy for IRCC-GC-TEP	184
5.4	Comparison of maximum training time for IRCC-GC-TEP	186
5.5	Comparison of maximum number of epochs for IRCC-GC-TEP	186
5.6	Comparison of maximum classification accuracy for IRCC-GC-VEP	195
5.7	Comparison of maximum training time for IRCC-GC-VEP	197
5.8	Comparison of maximum number of epochs for IRCC-GC-VEP	197
5.9	A typical representation of graphical user interface for IRCC	199
5.10	Subject seated on IRCC	200

## LIST OF ABBREVIATIONS

AAC	Augmentative and Alternative Communication
ALS	Amyotrophic Lateral Sclerosis
ANN	Artificial Neural Networks
ANOVA	Analysis of Variance
AP	Average Power
BMI	Brain Machine Interface
BMI-N	Brain Machine Interface for Navigation
BMI-SC	Brain Machine Interface for Speech
CA	Classification Accuracy
CC	Customized Classification
CNS	Central Nervous System
CRP	Corneoretinal Potential
CT	Computational Time
DE	Differentially Enabled
EEG	Electroencephalography
EMG	Electromyogram
EOG	Electrooculogram
ERP	Event Related Potentials
fMRI	Functional Magnetic Resonance Imaging
fNIR	Functional Near-Infrared Imaging
HMI	Human Machine Interface
HOS	Higher Order Statistics
ICA	Independent Component Analysis
IIR	Infinite Impulse Response Filters

IRCC	Intelligent Robot Chair with Communication Aid
IRCC-CC	IRCC System in Customized Classification System
IRCC-CC-TEP	IRCC System for TEP Database in Customized Mode
IRCC-CC-VEP	IRCC System for VEP Database in Customized Mode
IRCC-GC	IRCC System in Generalized Classification System
ITR	Information Transfer Rate
KNN	K-Nearest Neighbor
LDA	Linear Discriminant Analysis
MEG	Magnetoencephalography
MI	Motor Imaginary
MLNN	Multilayer Neural Network
MOH	Ministry of Health Malaysia
MREC	The Medical Research & Ethics Committee
NMD	Neuromuscular Disorders/Diseases
NMRR	National Medical Research Registration
P300	P for positive, 300 for the 300-millisecond delay
PET	Positron Emission Tomography
PSD	Power Spectral Density
QoL	Quality of Life
SC	Speech Communication
SCP	Slow Cortical Potentials
SE	Sensitivity
SNR	Signal to Noise Ratio
SP	Specificity
SSVEP	Steady State Visually Evoked Potentials

SVM	Support Vector Machine
TEP	Thought Evoked Potentials
TTD	Thought Translation Device
TVEPs	Transient VEPs
VEP	Visually Evoked Potentials
WHO	World Health Organization
WSS	Wide Sense Stationary

©This item is protected by original copyright

## LIST OF SYMBOLS

$\alpha$	Alpha band
$H_a$	Alternative hypothesis
$\Delta F$	Bandwidth
$\beta$	Beta band
$\delta$	Delta band
$\gamma_1$	Gamma 1 band
$\gamma_2$	Gamma 2 band
$\mu$	Mean
$\mu$ and $\beta$ rhythm	Sensorimotor rhythms
$\sigma$	Standard deviation (SD)
$\theta$	Theta band (4- 8 Hz)
$r_{\delta_i}^j, r_{\theta_i}^j, r_{\beta_i}^j, r_{\alpha_i}^j, r_{\gamma_1 i}^j$ and $r_{\gamma_2 i}^j$	Auto-correlation sequence of delta, theta, alpha, beta, gamma-1 and gamma-2 frequency bands.
$r_{\delta_i, \delta_{i+1}}^j, r_{\theta_i, \theta_{i+1}}^j, r_{\beta_i, \beta_{i+1}}^j, r_{\alpha_i, \alpha_{i+1}}^j, r_{\gamma_1 i, \gamma_1 i+1}^j$ and $r_{\gamma_2 i, \gamma_2 i+1}^j$	Cross-correlation sequence of two consecutive frames in each frequency bands (delta, theta, alpha, beta, gamma-1 and gamma-2).
$r_{\delta_i, \theta_i}^j, r_{\delta_i, \alpha_i}^j, r_{\delta_i, \beta_i}^j, r_{\delta_i, \gamma_1 i}^j, r_{\delta_i, \gamma_2 i}^j, r_{\theta_i, \alpha_i}^j, r_{\theta_i, \beta_i}^j, r_{\theta_i, \gamma_1 i}^j,$ $r_{\theta_i, \gamma_2 i}^j, r_{\alpha_i, \beta_i}^j, r_{\alpha_i, \gamma_1 i}^j, r_{\alpha_i, \gamma_2 i}^j, r_{\beta_i, \gamma_1 i}^j, r_{\beta_i, \gamma_2 i}^j, r_{\gamma_1 i, \gamma_2 i}^j$	Cross-correlation sequence for the 15 combination of six frequency bands
$r_{T_3 i T_4 i}^{fb}, r_{T_3 i C_3 i}^{fb}, r_{T_3 i C_4 i}^{fb}, r_{T_3 i P_3 i}^{fb}, r_{T_3 i P_4 i}^{fb}, r_{T_3 i O_1 i}^{fb},$ $r_{T_3 i O_2 i}^{fb}, r_{T_4 i C_3 i}^{fb}, r_{T_4 i C_4 i}^{fb}, r_{T_4 i P_3 i}^{fb}, r_{T_4 i P_4 i}^{fb}, r_{T_4 i O_1 i}^{fb},$ $r_{T_4 i O_2 i}^{fb}, r_{C_3 i C_4 i}^{fb}, r_{C_3 i P_3 i}^{fb}, r_{C_3 i P_4 i}^{fb}, r_{C_3 i O_1 i}^{fb}, r_{C_3 i O_2 i}^{fb},$	Cross-correlation sequence for the 28 combination of eight electrode channels

$r_{C4_iP3_i}^{fb}, r_{C4_iP4_i}^{fb}, r_{C4_iO1_i}^{fb}, r_{C4_iO2_i}^{fb}, r_{P3_iP4_i}^{fb}, r_{P3_iO1_i}^{fb},$   
 $r_{P3_iO2_i}^{fb}, r_{P4_iO1_i}^{fb}, r_{P4_iO2_i}^{fb}, r_{O1_iO2_i}^{fb}$

$r_{Y_1Y_2}(h)$	The cross correlation of two length Y deterministic inputs
Ag	Silver metal
AgCl	Salt—silver chloride
$B(f1, f2)$	Bispectrum in the bifrequency ( $f_1, f_2$ )
C3 and C4	Central lobe
$CP_i^j$	Change in powers
$DA_i^j$	Differential asymmetry
dB	Decibel
$df$	Degrees of freedom
$f_1, f_2$	Frequencies
F-value	Critical value for the f distribution
$h$	Lag
$H_0$	Null hypothesis
$k$	Kappa
$M$	Vector length
$M_{CEC}$	Mean features of the cross-correlated frame based combination of electrode channels
$M_{CF}$	Mean features of the Cross-Correlated Two Consecutive Frame based Spectral Bands
$M_{CFB}$	Mean features of the Cross-Correlated Frame Based Combination of Spectral Bands

$M_{CFW}$	Mean features of the auto-correlated frame wise spectral bands
O1 and O2	Occipital lobe
P3 and P4	Parietal lobe
$p$ -value	Probability of obtaining test statistical test
$RA_i^j$	Rational asymmetry
$RP_i^j$	Relative powers of frequencies
$SD_{CEC}$	Standard deviation features of the cross-correlated frame based combination of electrode channels
$SD_{CF}$	Standard deviation features of the Cross-Correlated Two Consecutive Frame based Spectral Bands
$SD_{CFB}$	Standard deviation features of the cross-correlated frame based combination of spectral bands
$SD_{CFW}$	Standard deviation features of the auto-correlated frame wise spectral bands
$SP_i^j$	Sum of the powers
T3 and T4	Temporal lobe
$Y(f)$	Discrete Fourier Transform (DFT) for deterministic signals
$Y^*(f_1 + f_2)$	Complex conjugate
$YF_i^{j2}$	Whole spectrum (0.1 – 100 Hz)
$Yf_i^j$	Specified frequency band signal

## **Reka Bentuk dan Pembangunan Sistem Kawalan secara Pemikiran untuk Kerusi Robot Pintar dengan Komunikasi Verbal**

### **ABSTRAK**

Pergerakan asas seperti berjalan, dan komunikasi adalah keperluan asas manusia dalam kehidupan seharian. Masyarakat kurang upaya (DE) mempunyai penghadan perangkap yang berubah antara aktiviti utama atau rumit seperti kelemahan otot-otot, kekejangan, masalah berkaitan pergerakan, strok, masalah penghadaman dan dysarthria. Dalam kes-kes ini, isyarat Electroencephalogram (EEG) digunakan sebagai ukuran pada aktiviti otak yang bertanggungjawab untuk mengawal pergerakan otot voluntari menerusi sistem saraf boleh digunakan untuk membentuk sistem komunikasi atau antara muka mesin otak (BMI). Kajian ini memberi tumpuan kepada analisis pelbagai domain frekuensi algoritma untuk menentukan isyarat-isyarat pelayaran dan komunikasi. Analisis ini digunakan untuk membangunkan kerusi robot pintar berasaskan ECG dengan bantuan komunikasi (IRCC). IRCC melibatkan klasifikasi isyarat pelayaran (ke depan, kiri, kanan & rehat) dan isyarat-isyarat yang berkaitan dengan ucapan (ya, tidak dan Bantuan), untuk menyediakan satu sistem navigasi dengan bantuan komunikasi untuk pesakit DE. Dua puluh sihat naif-, umur-, dan jantina- yang memenuhi kriteria mengambil bahagian dalam prosedur pengumpulan data dimana isyarat EEG lapan saluran tanpa wayar dirakam. Dua paradigma ringkas dilaksanakan berdasarkan pemikiran (TEP) dan potensi visual (VEP) untuk menentukan korelasi antara dinamik otak dan IRCC. Tambahan pula, data-data yang dibangunkan dianalisis dalam mod ubahsuai dan mod umum. Isyarat gelombang otak yang diperolehi itu di pra-process untuk membuang gelombang gangguan dan dibahagikan kepada sampel yang sama panjang. Isyarat itu dikategorikan kepada enam jalur frekuensi, (iaitu Delta, Theta, Alpha, Beta, Gamma-1 dan Gamma-2), dan digunakan untuk mengekstrak ciri-ciri tertentu. Untuk mengklasifikasikan IRCC, empat kaedah pengekstrakan frekuensi domain dibandingkan (spektrum perintah tinggi (HOS), analisis korelasi silang, analisis kuasa band (BP) dan ketumpatan kuasa spektrum (PSD)), dan tiga pendekatan yang berbeza berdasarkan teknik silang korelasi untuk menganggarkan saling bergantung di antara isyarat bingkai, jalur frekuensi dan kedudukan elektrod (iaitu ciri statistik menggunakan salib berkait rapat dua bingkai berturut-turut band spektrum berasaskan (CF), ciri-ciri statistik menggunakan silang dikaitkan bingkai gabungan berdasarkan jalur spektrum (CFB) dan ciri-ciri statistik menggunakan silang dikaitkan bingkai gabungan berdasarkan saluran elektrod (CEC)). Di samping itu, ciri-BP telah dianalisis dalam lima teknik yang berbeza untuk mengenal pasti perkaitan di antara IRCC dan spektrum kuasa dalam setiap jalur frekuensi, dan semua jalur frekuensi. Tiga klasifier berbeza seperti Rangkaian Neural banyak lapisan (MLNN), mesin sokong vektor (SVM), dan K- Jiran terdekat (KNN) telah digunakan untuk mengkaji prestasi semua ciri-ciri yang diekstrak. Skim sepuluh kali ganda-silang pengesahan telah digunakan untuk mengesahkan dan ujian kebolehpercayaan model pengelasan. Daripada keputusan, dapat disimpulkan bahawa band analisis kuasa yang dicadangkan berdasarkan analisis frekuensi band individu telah mendapatkan ketepatan pengelasan minimum (Mean  $\pm$  SD), 55.42%  $\pm$  2.29 untuk CC-TEP-CP, 63.80%  $\pm$  1.63 untuk CC-VEP- RA, 53.76%  $\pm$  5.85 untuk GC-TEP-CP dan 54.33%  $\pm$  2.25 untuk GC-VEP, yang menunjukkan bahawa jalur frekuensi individu mungkin tidak menggambarkan tugas IRCC. Manakala, analisis berdasarkan silang korelasi cadangan yang lebih baik dengan ketepatan pengelasan minimum maksimum 98.8% (TEP) mata pelajaran 17 dan 99.3% (VEP) bagi Subjek 17. Selanjutnya, sistem IRCC-GC mempunyai 89.44%  $\pm$  1.47 (min  $\pm$  SD) untuk GC-TEP-

CEC-SD dan  $88.93\% \pm 1.47$  (Min  $\pm$  SD) untuk GC-VEP-CEC-SD masing-masing. Keputusan yang diperoleh memberangsangkan dengan data eksperimen; ia boleh digunakan untuk mengemudi kerusi roda dan juga untuk komunikasi ucapan menggunakan paradigma ganjil.

©This item is protected by original copyright

## **Design and Development of a Thought Controlled Intelligent Robot Chair with Communication Aid**

### **ABSTRACT**

The fundamental movements like walking and speech communications are the basic needs of human beings in their daily life. Differentially Enabled (DE) communities have functional limitations that vary from primary/complicated activities such as weakening of the muscles, spasms, movement related problems, stroke, trouble swallowing and dysarthria. In these cases, Electroencephalogram (EEG) signals, being a measure of brain activity, which is responsible for the control of voluntary muscle movements through nervous system can be used to develop an alternative communication system or Brain Machine Interface's (BMI). This research focuses on analyzing different frequency domain algorithms to recognize the navigational tasks along with communication tasks to develop an EEG based intelligent robot chair with communication aid (IRCC). IRCC involves classification of navigational tasks (Forward, Left, Right & Relax) and tasks related to speech (Yes, No and Help), to provide a navigation system with communication aid for the DE patients. Twenty healthy naive-, age-, and gender-matched normal subjects were participated in the data collection procedure while eight-channel wireless EEG signal was being recorded. Two simple data acquisition paradigms were implemented based on thought evoked potentials (TEP) and visually evoked potentials (VEP) to determine the significant correlations between the brain dynamics and IRCC tasks. Furthermore, the developed database was analyzed in both customized modes and generalized modes. The recorded brain wave signals are preprocessed to remove the interference waveforms and segmented into frame samples of equal length. The frame signals are categorized into six frequency band signals, (namely Delta, Theta, Alpha, Beta, Gamma-1 and Gamma-2), and used to extract the features. To classify the IRCC tasks, four distinctive frequency-domain feature extraction methods were compared (namely higher order spectra (HOS), cross correlation analysis, band power (BP) analysis and power spectral density (PSD)). Also, three different approaches based on cross-correlation technique are proposed to estimate the interdependence between the frame signals, frequency bands and electrode positions (namely, statistical features using cross correlated two consecutive frames based spectral bands (CF), statistical features using cross correlated frame based combination of spectral bands (CFB), and statistical features using cross correlated frame based combination of electrode channels (CEC)). Further, the BP features were also analyzed in five different techniques to identify the interrelation between IRCC tasks and power spectrum in each frequency band, and all the frequency bands. Three different classifiers such as Multilayer Neural Network (MLNN), Support Vector machines (SVM), and K-Nearest Neighbor (KNN) were used to investigate the performance of all the extracted features. Ten-fold-cross-validation scheme was used for validating and testing the reliability of the classifier models. From the results, it is inferred that that the proposed band power analysis based on individual frequency band analysis has obtained minimal classification accuracy (Mean  $\pm$  SD), 55.42 %  $\pm$  2.29 for CC-TEP-CP, 63.80 %  $\pm$  1.63 for CC-VEP-RA, 53.76 %  $\pm$  5.85 for GC-TEP-CP and 54.33 %  $\pm$  2.25 for GC-VEP, which shows that individual frequency bands may not reflect the IRCC tasks. Whereas, the proposed cross-correlation based analysis have better performance with a mean-maximum classification accuracy of 98.8 % (TEP) for subject 17 and 99.3 % (VEP) for Subject 17. Further, the IRCC-GC system has 89.44 %  $\pm$  1.47 (Mean  $\pm$  SD) for GC-TEP-CEC-SD and 88.93 %  $\pm$  1.47 (Mean  $\pm$  SD) for GC-VEP-CEC-SD respectively. Thus, the results obtained were promising with the experimental data; it can be used to navigate a wheelchair and also for speech communications using oddball paradigm.